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Evaluation on Ecological Sustainability in Gansu Province Based on a Three-Dimensional Ecological Footprint Model

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Abstract. In this paper, we build a model based on the notion of green development that may be used to assess a three-dimensional ecological footprint. We design it by calculating two indicators, namely, footprint size and footprint depth. We perform quantitative research on ecological sustainable development. Based on our results, from 2010 to 2020, the per capita ecological footprint and ecological carrying capacity generally displayed a varying rising trend; the depth of the footprint has been maintained at 1.1364 gha/cap, and it is clear that the ecological footprint has constantly exceeded the ecological carrying capacity, which means that from 2010 to 2020, Gansu Province's ecological and economic development was in deficit. Based on these findings, we offer sound recommendations for the ecological environment's sustainable development in Gansu Province.

Keywords. Ecological footprint, ecological carrying capacity, three-dimensional ecological footprint, Gansu Province, sustainable development

1. Introduction

The issue of coordinating ecological and economic development has grown in importance as a result of the economy's rapid growth and the improvement in people's standards of living, and the effects of human activity on the environment have also gotten stronger. Research in ecological economics has focused increasingly on how to deal with the interaction between natural resources and social and economic growth [1]. In 1992, Canadian ecological economist Ress [2] first put up the idea of an ecological footprint (EF), which was later developed by Wackernage [3]. It has received much study and used both domestically and internationally.

In recent years, many researchers have conducted studies on issues related to ecological footprints. For example, Sonia and Samir diagnosed the fishery resource demand of an Algiers fishing port using the principle of ecological footprint [4]. In 2009, Niccolucci incorporated depth into the EF model, establishing a three-dimensional ecological footprint (EF_{3D}) [5]. Fang et al. was the first to use the EF_{3D} in China [6]. The EF_{3D} model was used by Zhu et al. to analyze sustainability in the present and the future as well as whether Chongqing's natural resource system could

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support the city's current social economy development mode [7]. In recent years, under the interactive pressure of rapid economic development and global climate change in Gansu Province, the natural state of the provincial capital has been continuously degraded, and the remaining open space has been squeezed [8]. Gansu Province is in a state of ecosystem degradation and suffers frequent ecological environment problems. This study was performed to respond to the national mood, which favors the development of an ecological civilization system, promotes the construction of an ecological society, and promotes the harmonious coexistence of man and nature. We selected this area as the research sample area to discuss the sustainable development of Gansu Province. For the implementation of regional sustainable development, the research in this paper may be practically significant.

2. Materials and Methods

2.1. Study Area

The province of Gansu has a total size of 425,800 square kilometers and is rich in biological and mineral resources. It is located in Northwest China. In the province's land area in 2020, arable land accounts for 12.62%; garden land accounts for 0.60%; forest land accounts for 14.31%; grassland accounts for 33.28%; urban villages and industrial and mining land account for 1.88%; transportation accounts for 0.64%; the land for water and water conservancy facilities accounts for 1.75%; other land accounts for 34.92% (http://www.gansu.gov.cn/).

2.2. Data Sources

Socioeconomic data from the Gansu Statistical Yearbook 2010–2020 (http://tjj.gansu.gov.cn) were predominantly used in this study. In the “National Ecological Footprint” report from 1997, Wachernagel published an equilibrium factor. In our study, we used that factor along with 1993 data from the United Nations Food and Agriculture Organization on average production levels of biological resources around the world [9]. The land use types in the basin are grouped into six categories here according to the “Land Use Status Classification” standard (http://www.stats.gov.cn/). The biological productivity of various types of land in Gansu Province is represented in Table 1 as a percentage.

Table 1. Details of the land types in the EF account.

Land type	Indicator details	Equilibrium factor	Production factor
Fossil energy	Coke, gasoline, natural gas	1.10	0.00
Building area	Electricity	2.80	1.66
Cultivated area	Wheat, grains, beans, corn, potatoes, cotton, sugar beets, Vegetables, oilseeds	2.80	1.66
Grass area	Meat, poultry, eggs, dairy, wool	0.50	0.19
Woodland	Fruit	1.10	0.91
Water area	Aquatic products	0.20	1.00

2.3. Research Methods

The ecological footprint model has undergone two evolutionary processes. The one-dimensional ecological footprint is mainly to calculate the degree of human resource utilization and convert biological resources into land areas that can be used for unified comparison [10]. That is, to calculate EF, use the following formula.

$$\mathrm{ef} = \sum r_j \times (c_i / p_i) \qquad j = 1, 2 \cdots 6 \tag{1}$$

$$\mathrm{EF} = N \times \mathrm{ef} \tag{2}$$

where, ef is the per capita ecological footprint (hm^2/cap); r_j is the equilibrium factor of Gansu Province; i is the different consumption item types; j is the different land types; c_i is per capita consumption of i commodities; p_i is the global average output of the i-type projects; N is the total population of the region (cap).

The calculation of carrying capacity is added to the two-dimensional EF based on one-dimensional EF. Ecological carrying capacity (EC) is the total amount of arable land that can supply the materials and energy needed by a community. The idea of ecological profit and loss is developed to determine if the regional EC can support human production activities.

$$\mathrm{ec} = \sum a_j \times r_j \times y_j \tag{3}$$

$$\mathrm{EC} = \mathrm{ec} \times N \tag{4}$$

$$\mathrm{ED} = \mathrm{EF} - \mathrm{EC} \tag{5}$$

where, ec is the per capita ecological carrying capacity (hm^2/cap); ED the ecological profit and loss; a_j is the per capita biological production area of the j-type projects; y_j is the production factor.

The following is the EF_{3D} calculating formula:

$$\mathrm{EF}_{\mathrm{size}} = \sum Min\{\mathrm{EF}, \mathrm{EC}\} \tag{6}$$

$$\mathrm{EF}_{\mathrm{depth}} = 1 + \frac{\sum Max\{\mathrm{EF} - \mathrm{EC}, 0\}}{\sum \mathrm{EC}} \tag{7}$$

$$\mathrm{EF}_{3\mathrm{D}} = \mathrm{EF}_{\mathrm{depth}} \times \mathrm{EF}_{\mathrm{size}} \tag{8}$$

where, EF_{size} is ecological footprint size (hm^2) and EF_{depth} is ecological footprint depth.

3. Results and Discussion

3.1. Dynamic Evolution of the Per Capita EF and EC in Gansu Province from 2010 to 2020

The ef, ec, and ED in Gansu Province from 2010 to 2020 were calculated using a technique discussed in a previous work [11], where EC×0.88 was used to represent the available ec (since after deduction, 12 percent of the land designated for biodiversity protection should be set aside). As shown in Table 2, the per capita EF in Gansu increased from 2.5721 hm^2 in 2010 to 3.0689 hm^2 in 2015, with changes in the period, finally reaching 3.2039 hm^2. The overall trend is still upward. The EC per capita in Gansu Province increased from 2.2634 hm^2 in 2010 to 2.7007 hm^2 in 2015 and decreased to 2.5451 hm^2 in 2016, finally reaching 2.8194 hm^2. From 2010 to 2015, the ef and the available ec in Gansu Province showed the same trend. The change in ED was caused by both EF and EC; ED also increased gradually from 2010 to 2015, after which it decreased, but it then finally increased to 0.3845 hm^2.

Table 2. ef, ec and EF_{3D} from 2010 to 2020.

Year	Per capita ecological footprint (balanced)	Total available area for ecological carrying capacity (minus 12%)	Ecological deficit	Ecological footprint size (EF_{size})	Ecological footprint depth (EF_{depth})	Three-dimensional ecological footprint (EF_{3D})
2010	2.5721	2.2634	0.3086	2.2634	1.1364	2.5721
2011	2.6481	2.3304	0.3178	2.3304	1.1364	2.6481
2012	2.7951	2.4597	0.3354	2.4597	1.1364	2.7951
2013	2.8501	2.5081	0.3420	2.5081	1.1364	2.8501
2014	2.9553	2.6007	0.3546	2.6007	1.1364	2.9553
2015	3.0689	2.7007	0.3683	2.7007	1.1364	3.0689
2016	2.8921	2.5451	0.3471	2.5451	1.1364	2.8921
2017	2.9059	2.5572	0.3487	2.5572	1.1364	2.9059
2018	2.8851	2.5389	0.3462	2.5389	1.1364	2.8851
2019	2.9069	2.5580	0.3488	2.5580	1.1364	2.9069
2020	3.2039	2.8194	0.3845	2.8194	1.1364	3.2039

The proportion of land use types in per capita EF and EC was further analyzed. From Figure 1, it can be seen that the grassland area accounted for the highest proportion of the ef, ranging from 33.3391% to 36.6304%. The proportion of fossil energy (29.5203%–32.9518%) and cultivated land (30.0183%–32.3708%) was comparable. Building area showed a steady growth trend from 0.6337% to 1.1205%. Woodland (0.2904%–0.3652%) and water area (1.2141%–1.8051%) had lower proportions. In terms of the percentage of terrain types having ec, the highest was cultivated land (89.0345%–91.2255%), followed by grassland area (19.8093%–21.7634%), woodland (0.3936%–0.4972%), and water area (0.0697%–0.1099%). The proportion of fossil energy was 0. As shown, cultivated land was the dominant land type, while the proportions of woodland and water area were very small, and there was no land relevant to fossil energy among Gansu Province land use types. Moreover, the year-to-year trends for each land use type are minimal and basically level-off.

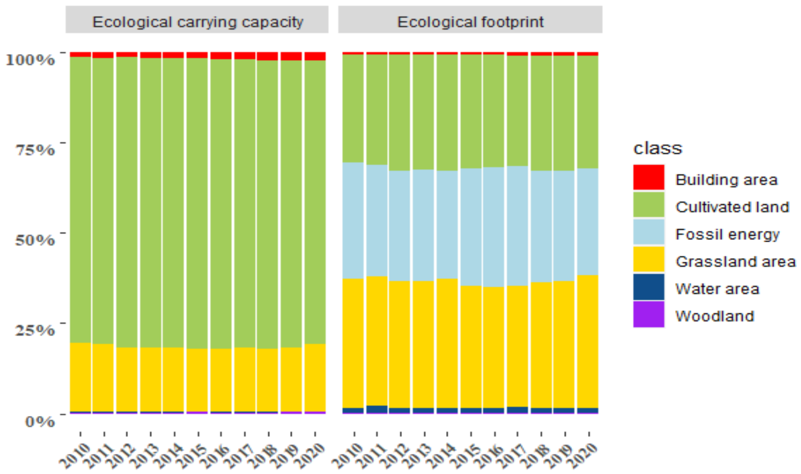

Figure 1. The composition ratio of ef and ec land types in Gansu Province from 2010 to 2020.

3.2. Three-Dimensional Ecological Footprint

According to Table 2, Gansu's EF_{3D} climbed from 2.5721 hm^2 in 2010 to 3.0689 hm^2 in 2015 and then declined to 2.8921 hm^2 in 2016, with variations over the course of the time, ultimately reaching 3.2039 hm^2. We can also see that the EF_{depth} has consistently exceeded 1 and the EF has consistently exceeded the EC, indicating that from 2010 to 2020, Gansu Province's ecological and economic development was in deficit.

The formation of an ecological deficit shows that Gansu Province's population is using its natural resources at a rate that exceeds the EC limit set by the natural system, indicating that the province is currently experiencing unsustainable growth. The ef of Gansu Province has already exceeded the ec of the province, but it is still smaller than the national and global ec supply. During this period, Gansu Province can be called unsustainable on the local, national, and global levels.

4. Conclusion

Based on EF theory, this research develops an EF and EC model. We calculated the ef, ec and analyzed their changing trends. On the basis of the EF, we introduced the EF_{depth} to establish an EF_{3D}, and calculated the surplus of the EF and the EF_{3D}. We drew the following conclusions: EF, EC, and EF_{3D} had the same trends, and they all increased gradually; the dominant land use type in Gansu Province is cultivated land, and the proportion of woodland and water area is very small. Each land use type experiences very little annual change; from 2010 to 2020, the EF of Gansu Province stayed higher than the EC, indicating that the province's ecological and economic development has lagged behind.

We present the following pertinent recommendations based on these findings for the long-term development of the ecological economy in Gansu Province: the development of Gansu Province continues to exceed the flow of resources, and the cumulative effect of the consumption of stock resources is increasingly prominent, mostly seen in the steadily rising per-person footprint of fossil energy and cultivated land. Under the presumption of environmental protection, building a reasonable consumption model, and strengthening the construction of an ecological civilization, we encourage low-carbon green consumption and clarify the focus of regional ecological environmental protection and economic development. Using efficient and environmentally friendly development techniques in major development regions may be the best course of action.

Acknowledgments

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